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CALCULATIONS OF VOLUME AND WEIGHT REDUCTION IN THE CONCENTRATION OF FRUIT JUICES

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TWO TABULATIONS are presented, one showing weight reductions related to various reductions in volume and one showing volume reductions related to various reductions in weight. The range covered is from 4 to 40 percent of soluble solids in the original juices. Volume and weight reductions range from 1.5:1.0 to 10.0:1.0.

CALCULATIONS OF VOLUME AND WEIGHT REDUCTION IN THE CONCENTRATION OF FRUIT JUICES

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The food processing industry is turning more and more to the production of foods that reduce packaging, shipping, and storage costs and also increase their convenience in use in homes, in the food-service institutions, and in the remanufacturing trade. Rapid growth has taken place in the production of concentrated juices and of packaged ready-to-serve frozen foods. Both groups of foods make possible savings in the above-mentioned costs through elimination of water, waste material, or both. To a considerable extent this trend to more concentrated foods is made possible by improved processing techniques, greater use of refrigeration, and better packaging. It is certain that as the food processing and distribution technologies advance, further progress will be made in the development of concentrated foods.

The economies that may be achieved in package, storage, and distribution costs through elimination of waste or unnecessary parts of the product serve materially to bring about these technological advances. Engineering and economic studies are important parts of the sound development of concentrated products to a position of commercial feasibility. Such studies require certain basic data on weight reduction, amount of water to be evaporated or waste material to be removed, package and shipping weights, container requirements, and other quantitative data.

For those concerned with juice concentrates, this publication contains tabulations showing the weight reductions related to various reductions in volumes (Table 1) and also volume reductions related to various reductions in weight (Table 2). Over a range of 4 to 40 percent soluble solids in the original juices, data are presented showing associated volume and weight reductions ranging from 1.5:1.0 up to 10.0:1.0 and the resulting percentages of soluble solids of the concentrates.

For example, orange juice having a soluble-solids content of 12 percent is concentrated 4-fold on a volume basis. Table 1 shows that the concentrate with a soluble solids of 42.3 percent represents a weight reduction of 3.52 to 1. When strawberry juice, for example, with a soluble solids content of 8 percent is concentrated to 56 percent, weight is reduced from 7 to 1. Table 2 shows that the corresponding volume reduction is 8.59 to 1.

How Data Were Calculated

The data presented are based upon simple formulas expressing a material (sugar) balance between the initial juice and the concentrate.

For volumetric relationships, let

P_j = lbs. sugar in 1 gallon of initial juice

1/ Agricultural Research Service, United States Department of Agriculture.

Table 1 - Volume and weight reduction in the concentration of fruit juices with given volume reductions based on sucrose values at 20°C/4°C.

Soluble Solids in original juice (%)	Pounds of juice to make one pound of concentrate with volume reductions[1] as follows: 1.5		2		3		4		5		6		7		8		9		10	
	SS[2]	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.
4%	6.0%	1.49	7.9%	1.97	11.6%	2.91	15.3%	3.82	18.8%	4.71	22.3%	5.57	25.7%	6.41	28.9%	7.23	32.1%	8.03	35.2%	8.80
5	7.3	1.49	9.8	1.96	14.4	2.89	18.9	3.78	23.2	4.65	27.4	5.48	31.4	6.28	35.3	7.06	39.1	7.82	42.7	8.55
6	8.9	1.48	11.7	1.96	17.2	2.87	22.5	3.74	27.5	4.58	32.3	5.39	37.0	6.16	41.4	6.91	45.7	7.62	49.9	8.32
7	10.4	1.48	13.6	1.95	19.9	2.85	25.9	3.70	31.7	4.52	37.1	5.30	42.3	6.04	47.3	6.76	52.1	7.44	56.7	8.10
8	11.8	1.48	15.5	1.94	22.6	2.83	29.3	3.67	35.7	4.46	41.7	5.21	47.4	5.93	52.9	6.61	58.1	7.27	63.2	7.89
9	13.3	1.47	17.4	1.93	25.3	2.81	32.7	3.63	39.6	4.40	46.3	5.13	52.4	5.82	58.3	6.48	63.9	7.10	69.3	7.70
10	14.7	1.47	19.3	1.93	27.9	2.79	35.9	3.59	43.5	4.35	50.5	5.05	57.2	5.72	63.5	6.35	69.5	6.95	75.2	7.52
11	16.2	1.47	21.1	1.92	30.5	2.77	39.1	3.56	47.2	4.29	54.8	4.98	61.9	5.62	68.5	6.23	74.9	6.81	80.9	7.35
12	17.6	1.47	23.0	1.91	33.0	2.75	42.3	3.52	50.9	4.24	58.9	4.91	66.4	5.53	73.4	6.12	80.0	6.67	86.4	7.19
13	19.0	1.46	24.8	1.91	35.5	2.73	45.4	3.49	54.5	4.19	62.9	4.84	70.7	5.44	78.1	6.01	85.1	6.54		
14	20.5	1.46	26.6	1.90	38.0	2.71	48.4	3.46	57.9	4.14	66.8	4.77	75.0	5.36	82.6	5.90				
15	21.9	1.46	28.4	1.89	40.4	2.69	51.4	3.42	61.4	4.09	70.6	4.70	79.1	5.27	87.1	5.80				
16	23.3	1.46	30.2	1.89	42.9	2.68	54.3	3.39	64.7	4.05	74.3	4.64	83.1	5.20						
17	24.7	1.45	32.0	1.88	45.2	2.66	57.1	3.36	68.0	4.00	77.9	4.58	87.0	5.12						
18	26.1	1.45	33.7	1.87	47.6	2.64	60.0	3.33	71.2	3.96	81.5	4.53								
19	27.5	1.45	35.5	1.87	49.9	2.63	62.8	3.30	74.4	3.91	84.9	4.47								
20	28.9	1.45	37.2	1.86	52.2	2.61	65.5	3.28	77.5	3.87	88.3	4.42								
21	30.3	1.44	38.9	1.85	54.5	2.60	68.2	3.25	80.5	3.84										
22	31.7	1.44	40.6	1.85	56.8	2.58	70.9	3.22	83.5	3.80										
23	33.1	1.44	42.4	1.84	58.9	2.56	73.5	3.20	86.5	3.76										
24	34.4	1.44	44.1	1.84	61.2	2.55	76.1	3.17												
25	35.8	1.43	45.7	1.83	63.3	2.53	78.7	3.15												
26	37.2	1.43	47.4	1.82	65.5	2.52	81.2	3.12												
27	38.5	1.43	49.1	1.82	67.6	2.51	83.7	3.10												
28	39.9	1.43	50.7	1.81	69.8	2.49	86.1	3.08												
29	41.3	1.42	52.4	1.81	71.9	2.48	87.5	3.05												
30	42.6	1.42	54.0	1.80	73.9	2.46														
31	44.0	1.42	55.6	1.79	76.0	2.45														
32	45.3	1.42	57.3	1.79	78.0	2.44														
33	46.6	1.41	58.9	1.78	80.2	2.43														
34	48.0	1.41	60.5	1.78	82.0	2.41														
35	49.3	1.41	62.1	1.77	84.1	2.40														
36	50.6	1.41	63.6	1.77	86.0	2.39														
37	51.9	1.40	65.2	1.76																
38	53.3	1.40	66.8	1.76																
39	54.6	1.40	68.3	1.75																
40	55.9	1.40	69.9	1.75																

1/ Volume reduction = gallons of juice to make one gallon of concentrate. 2/ Soluble solids.

Table 2 - Volume and weight relationship in the concentration of fruit juices with given weight reductions based on sucrose values at 20°C/4°C.

Soluble solids in original juice (%)	Gallons of juice to make one gallon of concentrate with weight reductions[1] of: 1.5		2		3		4		5		6		7		8		9		10	
	SS[2]	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.	SS	lbs.
4%	6%	1.51	8%	2.03	12%	3.10	16%	4.20	20%	5.33	24%	6.50	28%	7.72	32%	8.97	36%	10.27	40%	11.61
5	7.5	1.52	10	2.04	15	3.12	20	4.25	25	5.42	30	6.64	35	7.92	40	9.25	45	10.63	50	12.08
6	9	1.52	12	2.05	18	3.15	24	4.30	30	5.51	36	6.79	42	8.13	48	9.54	54	11.02	60	12.59
7	10.5	1.52	14	2.06	21	3.17	28	4.36	35	5.61	42	6.94	49	8.35	56	9.85	63	11.44	70	13.13
8	12	1.52	16	2.07	24	3.20	32	4.41	40	5.71	48	7.10	56	8.59	64	10.18	72	11.88	80	13.71
9	13.5	1.53	18	2.07	27	3.23	36	4.47	45	5.82	54	7.26	63	8.83	72	10.52	81	12.35		
10	15	1.53	20	2.08	30	3.26	40	4.53	50	5.92	60	7.43	70	9.08	80	10.88				
11	16.5	1.53	22	2.09	33	3.29	44	4.59	55	6.03	66	7.61	77	9.35	88	11.26				
12	18	1.54	24	2.10	36	3.32	48	4.66	60	6.15	72	7.80	84	9.62						
13	19.5	1.54	26	2.11	39	3.35	52	4.72	65	6.26	78	7.99								
14	21	1.54	28	2.12	42	3.38	56	4.79	70	6.39	84	8.18								
15	22.5	1.55	30	2.13	45	3.41	60	4.86	75	6.51										
16	24	1.55	32	2.14	48	3.44	64	4.93	80	6.64										
17	25.5	1.55	34	2.15	51	3.47	68	5.00	85	6.77										
18	27	1.56	36	2.16	54	3.50	72	5.07												
19	28.5	1.56	38	2.17	57	3.54	76	5.15												
20	30	1.56	40	2.18	60	3.57	80	5.23												
21	31.5	1.57	42	2.19	63	3.61	84	5.30												
22	33	1.57	44	2.20	66	3.64	88	5.38												
23	34.5	1.57	46	2.21	69	3.68														
24	36	1.58	48	2.22	72	3.71														
25	37.5	1.58	50	2.23	75	3.75														
26	39	1.59	52	2.24	78	3.79														
27	40.5	1.59	54	2.25	81	3.82														
28	42	1.59	56	2.26	84	3.86														
29	43.5	1.60	58	2.27	87	3.90														
30	45	1.60	60	2.28																
31	46.5	1.61	62	2.29																
32	48	1.61	64	2.31																
33	49.5	1.61	66	2.32																
34	51	1.62	68	2.33																
35	52.5	1.62	70	2.34																
36	54	1.62	72	2.35																
37	55.5	1.63	74	2.36																
38	57	1.63	76	2.38																
39	58.5	1.64	78	2.39																
40	60	1.64	80	2.40																

1/ Weight reduction = pounds of juice to make one pound of concentrate. 2/ Soluble solids.

P_c = lbs. sugar in 1 gallon of concentrate
V = volumetric concentration ratio or "fold", the gallons of initial juice required to make 1 gallon of concentrate.

Since all of the sugar in the concentrate is derived from the initial juice, the number of gallons of initial juice required to supply the sugar in a gallon of concentrate is P_c/P_j, and

$$V = \frac{P_c}{P_j} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If sugar concentrations are expressed on a weight basis, a similar relationship may be derived for the weight concentration ratio or "fold." Degrees Brix is a measure of apparent pounds of sugar per pound of juice or concentrate, and so may be used for calculating weight relationships.

Let B_j = lbs. sugar in 1 lb. of initial juice
B_c = lbs. sugar in 1 lb. of concentrate
W = weight concentration ratio or "fold," the pounds of initial juice required to make 1 pound of concentrate.

Again, since all of the sugar in the concentrate is derived from the initial juice, the number of pounds of initial juice required to supply the sugar in a pound of concentrate is B_c/B_j, and

$$W = \frac{B_c}{B_j} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

A simple relationship between concentration by volume and concentration by weight may be obtained by dividing equation (1) by equation (2):

$$\frac{V}{W} = \frac{P_c \, B_j}{B_c \, P_j} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Examination of equation (3) shows that P_c/B_c is pounds of concentrate per gallon of concentrate, or a measure of the density of the concentrate. P_j/B_j is similarly a measure of the density of the initial juice. Since density is directly related to specific gravity,

$$\frac{V}{W} = \frac{S_c}{S_j} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where S_c is the specific gravity of the concentrate and S_j is the specific gravity of the initial juice.

With the volume reduction given, the formula becomes

$$W = \frac{V \, S_j}{S_c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

With the weight reduction given, the formula becomes

$$V = \frac{W \, S_c}{S_j} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Formulas (1), (2), (4), (5), and (6) can be used to calculate all needed information regarding relationships between weight and volume fold concentrations. The only limitations on their use are outlined in the following section.

Qualifications of the Data Presented

The data presented in this paper, as well as those presented by Moore (4) and Kreele (3), are based on sucrose values at 20°/4°C., as given in the sugar tables in the Handbook of Chemistry and Physics (2). Three questions arise in this analysis of the relation of volume and weight concentration wherein values for fruit juices are based on sucrose values:

1. Should solids be expressed in terms of Brix or soluble solids?
2. How are the soluble solids of the fruit juice determined?
3. What inaccuracies exist as the result of basing calculations on soluble solids rather than on total solids?

The solids content of a sugar solution is frequently expressed in terms of Brix, or percentage of sugar. Fruit juices, however, contain other solids in addition to sugar. It is a difficult task to determine a true Brix or sugar reading for a fruit juice. Hydrometer or refractometer readings are primarily a measure of soluble solids, although they are commonly referred to as Brix. It is probable that the other soluble solids in fruit juices have about the same characteristics as sugars; hence values based on the sugar tables can be assumed to apply. To avoid any possible misunderstanding in this paper, the term "soluble solids" instead of "Brix" will be used henceforth in the discussion and tabular material.

The method of determining soluble solids is not discussed here. It is assumed that a true soluble-solids value is available for a given juice or concentrate. Thus the correction of a refractometer reading for a component such as citric acid would have already been done. An exact application of data based on sucrose values would rest on the premise that fruit-juice solids are all sucrose or that fruit sugars and other constituents have physical properties similar to those of sucrose. Whether or not this is true, however, may be unimportant if it can be shown that the soluble solids value of a juice bears a constant relationship to total solids at each stage of concentration.

Another point to consider is the degree of accuracy needed for the purposes to which these data may be put. These data are intended to assist in rapid but approximate determinations of the relationship between volume and weight reductions, and minor deviations would be of no consequence. Another point that should be considered is that the errors that might be inherent in this analysis may be relatively insignificant when compared with the errors resulting from the physical limitations of accurate measurements of solids.

One clue to the relationship between Brix and total solids of one type of juice at different concentrations is found in a publication of the National Canners Association (1). Some of the values published there are shown below:

Brix	Total solids	Brix to solids ratio (calculated)
5.6%	6.0%	0.933
6.0	6.4	0.937
9.3	10.0	0.930
10.0	10.8	0.926
13.8	15.0	0.920
15.0	16.3	0.920
18.4	20.0	0.920
20.0	21.7	0.922
27.8	30.0	0.927
30.0	32.0	0.932
32.7	35.0	0.934

The average Brix-to-solids ratio of the values listed is 0.9274, making the greatest deviation from the average roughly 1 percent. The difference between the highest and lowest values is less than 2 percent. Thus the difference is one part in 50.

The relationships studied in the paper are within reasonable limits only if the insoluble-solids content of a juice is relatively low. This is true of most fruit juices, but there may be cases when the amount of insolubles is too great to ignore. An entirely different calculation would then be necessary, as values based upon the sugar tables would not apply.

Tabular Data

For starting juices ranging in 2-percent steps from soluble solids of 4 to 40 percent and for given volume concentrations up to 10 to 1, weight reductions are shown in Table 1. For given weight reductions, the associated volume reductions are shown in Table 2. Both tables also give the soluble solids of the concentrates at the various concentrations indicated. Intermediate values of both soluble solids and concentrations can be readily interpolated from the tables.

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